

## MODELING OF AIR-INFLATED WOVEN FABRIC STRUCTURES

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Pressurized fabric tubes (known as air beams) and air-inflated structures are considered to be valuable technologies for lightweight, rapidly deployable applications. During the past three decades, plain-woven fabrics have been utilized as structural materials in air-inflated systems resulting in rapidly deployable structures such as temporary shelters, tents, temporary bridges and space structures. Unlike metallic structures, air-inflated structures are primarily designed to be lightweight, have deployed-to-stowed volume ratios that can be on the order of 1000-to-1, and may be self-erecting. These applications typically employ pressurized fabric tubes as their basic load-carrying members. The advents of new fiber materials and weaving/braiding technologies have improved the versatility of pressurized fabric tubes to support significant external loads. Although these valuable technologies have been around for many years, they have not been refined to such a stage that reliable structures can be analytically designed and optimized. Predictive performance capabilities remain in their infancy when addressing survivability and sustainability concerns from the perspectives of fabric strength, stiffness and damage tolerance. Accordingly, there has been increasing interest from the US Army, Navy, Air Force, NASA and industry to model the mechanical behavior of pressurized woven fabric structures.

Woven air beams are discontinuous structures that consist of discrete fibrous tows (see Fig. (1)) and membrane-like bladders. It remains impossible to explicitly model all the tows that comprise an air beam and their tow-to-tow contact interactions that influence gross fabric structural behavior. In this research, the micromechanical effects of interacting tows have been studied through finite element models (FEM) containing tow-to-tow contact surfaces and nonlinear slip/stick conditions. A localized model of a patch consisting of a repetitive fiber placement pattern of the fabric, also referred to as a "unit cell", was introduced as shown in Fig. (2). The local unit cell models, consisting of woven tows, were created to characterize the effective constitutive relations of the fabric. The resulting effective material properties were then used as input to macromechanical continuum models. The macromechanical models preserved the micromechanical influences such as crimp on material behavior without subjecting the analysis to computational penalties associated with the explicit modeling approach. Once the

effective fabric properties were determined for a given pressure, material, denier and weave construction, they can be used to model straight or arched air beams regardless of size. Additionally, an experimental 4-point flexure set-up was designed and manufactured for testing of 2-inch diameter Vectran<sup>®</sup> (thermoplastic liquid crystal polymer) and PEN<sup>®</sup> (polyethylene naphthalate) air beams to validate the models.

The air beam mid-span deflections were measured as functions of inflation pressures, applied bending loads and loading rates as shown in Fig. (3). Plots of the effective elastic and shear moduli with respect to the pressure and friction coefficient were generated. It was determined that the effective elastic moduli,  $E_{11}$  and  $E_{22}$ , were functions of inflation pressure, the fabric material and the geometry of the weave. However, the fabric shear modulus,  $G_{12}$ , was shown to be independent of the tow elastic properties. While the elastic tow modulus of Vectran was approximately 5 times greater than that of the PEN tows, the load versus mid-span deflection curves for these two materials were similar at given pressures and loading rates. The shear modulus was analytically determined as a pressure-dependent, system property (see Fig. 4) of the assembled woven tows rather than a material property of the tows. Using a shear-deformable Timoshenko beam formulation with the analytical  $G_{12}$  values, it was shown that the transverse shearing components of the total mid-span deflections exceeded the bending components. Flexure behavior of the Vectran and PEN air beams were found to be nearly insensitive to the elastic tow moduli but highly dependent upon the pressure-induced  $G_{12}$  shear modulus resulting from rotational resistance generated through friction between contacting warp and weft tows. A quarter symmetry shell model of a 4-point flexure loaded Vectran air beam was generated using effective structural properties obtained from the unit cell model. As shown in Fig. (5), the transverse shear deformations dominated the flexure response. It was shown that woven air beams differ fundamentally from conventional metal and composite structures. In particular, the mechanical characteristics of plain-woven fabric air beams exhibit high non-linearity with dependence on the internal pressure and contact interactions among adjacent tows.

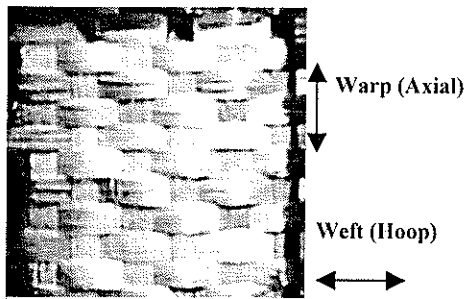


Fig. (1) Tow-Level Detail of Woven Air Beam

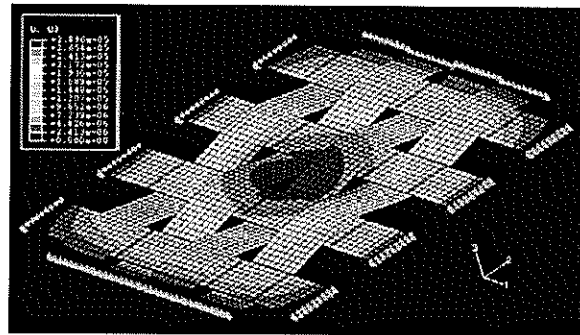


Fig. (2) Finite Element Model of Fabric Unit Cell

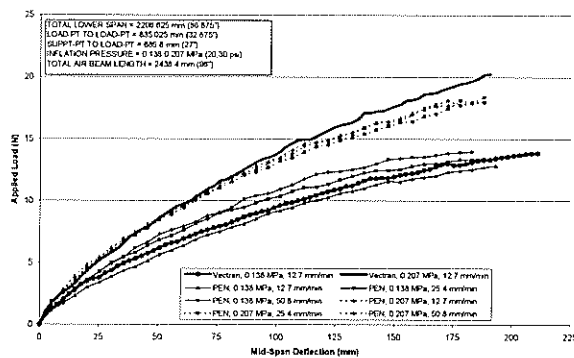


Fig. (3) Nonlinear Flexure Behavior of Vectran & PEN Air Beams with Pressure and Load Rate Dependence

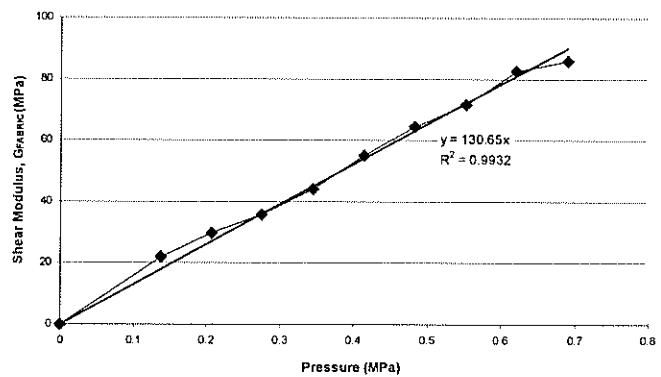


Fig. (4) Pressure-Dependent Shear Modulus,  $G_{12}$ , For 1500 Denier Vectran Woven Air Beam

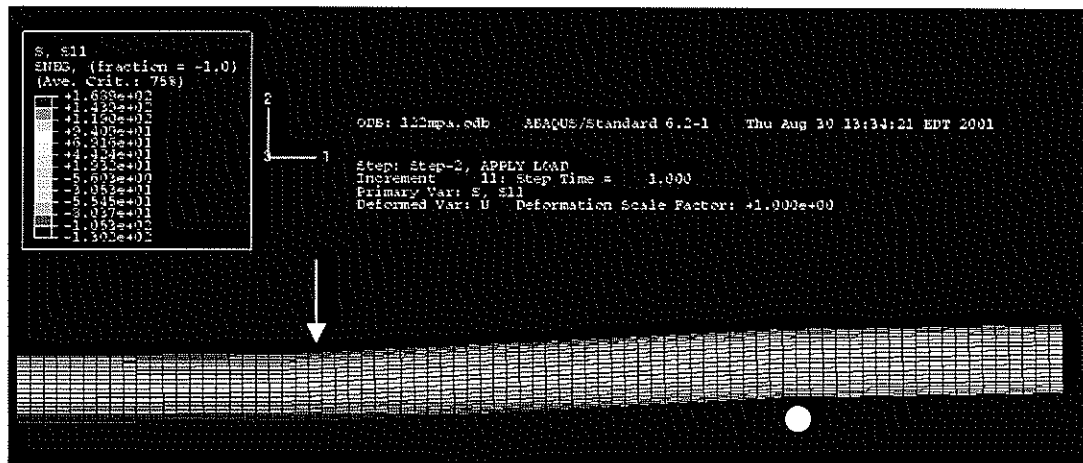


Fig. (5) Quarter Symmetry Vectran Shell Model Using Effective Structural Properties Based on Unit Cell Model Results